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THE ROLE OF WATER IN ENERGY DEVELOPMENT

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Abstract

One consequence of the recently increasing emphasis on energy development is public concern about the adequacy of ancillary natural resources, particularly water. This concern accompanies other water-related issues such as droughts, declining water tables, and increasing urbanization. But as the relatively new user on the water scene, energy attracts a major share of public attention.

The physical availability of water and the role of economics in water demand by energy are reviewed in this chapter. Also described are the social mechanisms through which the physical availability of water, the historical pattern of water use, and unresolved water issues combine to constrain and channel the energy industry's use of water. These mechanisms include the developing markets for water rights, the legal and administrative structure governing water allocation, the formation of social attitudes about water, and the political process that often implements concensus. The narrow physical interpretation commonly given to the question "Is there enough water?" is broadened to include the social dimension, the most important component of the question.

Water resource problems were featured in many articles and broadcasts during the past year. Although these reports addressed a wide variety of topics, including the antiquated state of some urban water delivery systems, the potential for severe drought, the depletion of the Ogallala Aquifer in the High Plains grain belt, opposition to water storage or conveyance projects (such as the Peripheral Canal in California), and contamination of drinking water, they reflect two persistent themes: the prospect of water shortages and an impending crisis. As a prime example, consider a cover article in US News and World Report (1) entitled "Water: Will We Have Enough to Go Around."

> Suddenly hundreds of local water problems across the country are merging into one enormous national crisis. How people respond ... could have a profound impact on US economic growth and social structure in the years ahead.

Perhaps statements such as these reflect journalistic hyperbole. Nevertheless, they indicate an increased popular concern with water and the need for more technical information (2).

In this chapter we consider a subsidiary theme--the adequacy of water supplies to accommodate energy development in the semi-arid western US. This subject became prominent in the wake of the 1973 oil embargo and resurfaced with subsequent OPEC price shocks," legislation to subsidize the synthetic fuels industry, and the current debate concerning coal leasing policy. Our purpose is not to review the technical literature. Rather, it is to address the layered perspectives on water- and energy-related issues. The technical literature since 1973 reflects an evolution through these perspectives: from physical, through economic and institutional, to the emerging perscriptions for water resources management.

At its most general level, the water and energy issue is a physical problem. Water requirements for energy development may exceed the available supply. Throughout the seventies, numerous studies, often supported by the Federal government, identified either basins in which water shortages were likely to occur, or energy demand scenarios that were infeasible because of water supply constraints. For example, see (3,4).

If one views the subject of water and energy as a resource allocation or economic problem, more optimistic conclusions are compelling. First, the long-run price elasticity of energy demand is higher than commonly supposed in the seventies. Second, the economics of mine-mouth electricity generation are often unfavorable compared with coal shipments to the demand regions. Together, these two observations imply lower production rates than originally projected in the energy resource regions of the West. Third, analysts recognize that energy firms demand rather than require water; as water becomes more scarce, firms employ new water-conserving technologies. Fourth, alternative supply sources to unallocated surface water are available. More importantly, markets that contribute to the allocation of water resources have developed in the West. Fifth, the energy sector has a greater ability to pay for water or for conservation technologies than most other sectors have. In summary, these five considerations result in lower energy-related water demand in the semi-arid West.

In the second section, we review the economics of water use in the energy industry. We describe water demand and supply at the plant level and report results of more aggregrated, basin-level analyses.

Economic analysis of water use suggests generally favorable prospects for energy development in the West from a water-related perspective. But, each analysis also highlights the persistence of political and economic conflicts in water allocation and the need for institutional change. Institutional considerations, the focus of many current water- and energy-related studies, are the topic of the third section of this paper. In the fourth section, we make two tentative observations about remaining issues in the everpresent conflict over water supplies in the West.

Water Use For Energy Production

The mix and quantity of factor inputs to production depend on the relative cost or availability of inputs. In most regions, water is inexpensive or even free. Not surprisingly, its use is quite intensive.

The budget for water use in the energy sector, compared for example to irrigated agriculture, is but a small fraction of total production costs. Capital and fuel costs dwarf water-use costs. Thus, the energy sector has an advantage in adapting to the new era of water scarcity. Energy can afford sharply higher payments to acquire water or capital investments (to conserve water) that have only slight or negligible effects on such fundamentals as selection of site, process, and output level.

In this section, we review water demand of and supply to the energy sector. To illustrate the interaction between energy development and water resources at the basin level, we present survey and modeling results.

Water Demand

There are four basic uses of water at energy conversion facilities: waste heat rejection or cooling, process use (as a boiler feed and a source of hydrogen for synthetic fuels), flue gas desulfurization, and solid waste disposal (in a slurry). Aside from the cost and availability of water, other factors influence water demand for these uses (5,6). These factors include production process characteristics, fuel quality (ash and sulfur content and heating value), degree of process water recirculation and reuse, the cost of water treatment technologies, residual discharge regulations, land disposal costs, and plant capacity factors. Process type and effluent discharge regulations are particularly important.

The production process determines the waste heat load and process water requirements, with considerable variation possible among processes. For example, the waste heat load at a coal-fired electric plant is one-third less than for an equivalent nuclear electric plant because of stack gas losses and slightly higher conversion efficiencies. A Lurgi coal gasifier can recover as much as 30% of the moisture in the raw coal feed whereas most second-generation gasifiers require a dry coal feed. Although the process type accounts for considerable variability in water demand, process selection normally is independent of water supply considerations.

Design for zero-discharge or containment of liquid effluents at the plant site is standard practice throughout the West (7). In the Colorado Basin, this is due to effective prohibition of industrial salt loading. In other basins, it arises from anticipation that the Environmental Protection Agency will eventually promulgate zero-discharge regulations, or it arises from the desire to avoid National Pollutant Discharge Elimination System permit reviews and potential delays. Because the most efficient waste water treatment option, distillation, compares favorably with the cost of land disposal or solar evaporation, the zero-discharge constraint promotes the maximum degree of water recirculation, reuse, and treatment (7,8).

Consider again the four basic uses of water for energy conversion. Table 1 presents estimates of water use for seven energy conversion processes at standard-size mine-mouth facilities. These estimates assume extensive water treatment and reuse and are approximate upper bounds on water use for new energy conversion plants in the West. It is apparent that cooling water consumption is the principal target of water conservation in the energy sector. Dry or wet/dry cooling provides the demand-side response to water scarcity.

In physical terms, electricity generation provides the greatest potential for water conservation with dry cooling. Evaporation of cooling water accounts for 90% or more of total water use, excluding mine use. Table 2 shows alternative cooling system costs ($/kW and mills/kWh) and break-even water-use costs. Compared to bus bar electricity costs (about $1 000/kW and

30 mills/kWh), the incremental costs of 40% and even conventional 10% wet/dry cooling systems seem tolerable. However, the break-even costs are high compared to typical costs of water acquisition, treatment, and disposal for 100% wet cooling systems at most Western sites.

The Electric Power Research Institute and US Department of Energy are investigating advanced dry cooling concepts that use ammonia in a phase change process, enhanced heat transfer surfaces in the steam condenser, and deluge systems for partial wet operation (9). Advanced cooling technologies, which provide cost savings of about one-third compared to conventional systems, are nearing commercial availability. Firm estimates of break-even water costs for advanced dry or wet/dry cooling systems are not available, but they may fall below $300/acre-ft indicating great commercial potential for advanced dry cooling technologies in the electric utility section in the next decade.

The potential for dry cooling at synthetic fuel plants is promising, even with conventional technologies because some waste heat loads occur at higher temperatures than the range typical of steam turbine condensers at electric plants. In fact, the water use estimates for synthetic fuel processes shown in Table 1 reflect extensive use of dry cooling even under the assumption that water supply is free. Cooling water consumption can be approximately halved from the estimates shown in Table 1 at incremental product costs of about 1% and break-even water supply costs of $80 to $1 300/acre-ft (10,12).

<u>Water Supply</u>

Although the hydrologic cycle is well known, for economic analysis it is convenient and sensible to consider water as a stock; it is sensible because that treatment is generally afforded by western state water law, by the doctrine of prior appropriation. One may identify four potential sources of supply to the energy sector: unallocated surface water, water in existing uses, groundwater, and waste water.

For many reasons, the quantity and price of water available in these supply categories are uncertain. First, there is a lack of data. In state water plans, for example, the data is fairly aggregate, omits price considerations, and provides superficial treatment of groundwater. Second, there is uncertainty concerning the definition of individual water rights, especially the consumption entitlement. Third, there are questions concerning the interpretation of existing law: for example, the degree of protection afforded adjacent or downstream water users in the case of a water transfer or application for a new groundwater withdrawal. Finally, there is the prospect of legislative change as a reaction to development. In any event, the steep break-even water-use costs for conventional, commercially available dry cooling technologies and the inelastic demand for process and other uses encourage energy firms to go to great lengths to acquire water.

Unallocated surface water is an increasingly rare phenomenon. The principal sources are existing or planned storage projects of the US Bureau of Reclamation, often at cost-based (inexpensive) prices of about $15/acre-ft. (This may be changing.) Although development of project water faces mounting obstacles from competing demands of the agricultural and municipal sectors and for instream uses (13), it is still common. Exxon, for example, recently signed a contract for up to 6 000 acre-ft/yr for its Colony oil-shale project.

In the future, water in existing uses will be the most important source of supply to accommodate development. Agriculture currently accounts for about 90% of water consumption in the West compared to less than 1% for the energy sector (see Table 3). In some basins, for high value crops like citrus, the value of water may approach $200/acre-ft but the marginal value in hay and alfalfa production (which predominates in the high-altitude, irrigated regions of the High Plains, Rocky Mountains, and Great Basin) is less than $10/acre-ft (14,15). For water-use reductions up to 40%, the marginal value in irrigation is still under $60/acre-ft.

North and South Dakota effectively prohibit transfer of water from irrigators to industrial users. In recent years, the Wyoming Board of Control denied or sharply reduced the quantity of water available as transfers to the energy sector (16). But there is evidence that such transfers are occurring throughout the West (Table 4) and that, even more frequently, the energy sector is purchasing and leasing irrigated land for future purposes.

The price of irrigation water varies widely depending on basin supply and demand. Generally one may say that farmers and ranchers value the market price of their water. In a well-publicized transaction, Intermountain Power Project purchased rights to 40 000 acre-ft in the Sevier Basin of Utah for $1 750/acre-ft (19). In a recent classified advertisement in the Wall Street Journal, a 3 000-acre cattle and sheep ranch in Rio Blanco County (the heart of Colorado oil-shale country) was listed. The ranch has "16 cfs early water," which exceeds 1 100 acre-ft/yr. If the entire value of the ranch were attributed to its water rights, that value would exceed $2 000/acre-ft, or $100-200/acre-ft on an annual, unit cost basis (20).

The stock of groundwater resources, compared to annual surface flows, is immense throughout basins of the West. The states' treatment of groundwater extraction varies considerably (21). Several states, including Montana and Nevada, restrict withdrawals to the rate of annual recharge. In Arizona many basins are closed to new appropriation. However, the energy sector is at considerable advantage because of its ability to pay. It can tap relatively deep (one thousand feet or more) or brackish aquifers, conduct hydrogeologic investigations, and thereby reduce or avoid interference with existing water users.

Potential sources of waste water include municipal sewage plants, uranium and oil-shale mines, and brackish return flows from irrigation. Compared to the other sources, potential waste water supplies are small, but such supplies match well the demands of the energy sector. Water-quality regulations often restrict the discharge of sewage or mine effluent. Each energy conversion facility can absorb flows up to 40 000 acre-ft/yr and can afford the investment in pipelines, reservoirs, and sediment treatment facilities.

At the plant level, the task of water acquisition seems tractable. However, it is also important to consider the aggregate water demands of the energy industry and the supply outlook at the basin level. The intense concentration of energy conversion plants in a few regions with relatively scarce water supplies may alter or qualify the favorable outlook for energy development.

Basin Analysis

We present two different approaches to basin or regional analysis: survey data of the current pattern of water use and results from an energy optimization model that incorporates water supply and demand. These approaches draw upon previous work examining the "water and energy" question.

Figures 1-3 present water-use data for electric generating plants projected to come on-line during the period 1980-1989 for selected river basins or states (22). Figure 1 shows that evaporative cooling continues to be the almost universal method of waste heat rejection. In fact, no commercial-scale sales of dry or wet/dry cooling systems to the utility industry are planned currently anywhere in the US. Figure 2 confirms that zero-discharge is standard practice in the West. New plants routinely operate cooling systems in the range of 10-25 cycles of concentration and reuse cooling tower blowdown for flue gas desulfurization or ash disposal (7). Figure 3 shows that, in the Colorado and Great Basins, utilities have turned to a variety of water-supply alternatives to surface water. By contrast, in the Upper Missouri Basin with its relatively abundant water supplies, surface water continues to be the favored source of supply. These survey data, which generally confirm findings drawn from consideration of water-use costs, indicate the response of the energy industry to water scarcity in different basins. Yet, one cannot blithely project these new patterns of water use for the future. Rapid growth of synthetic fuel markets, in particular, might reverse the optimistic, short- to mid-term prospects.

To examine the relationships between the scale of energy development and basin suppliers, we used the Los Alamos Coal Use Modeling System (LACUMS). (The Appendix presents a more detailed description of the model and the scenarios.) The model includes a forecast of water use patterns in the energy sector to the year 1995 (18). The energy demand scenario for the LACUMS analysis included an effective annual growth rate in electricity consumption in the US of 4.5% from 1980-1995. Further, LACUMS included 2 quads (10^{15} Btu) of shale oil production, 1.333 quads of high-Btu gas from coal, and 0.667 quad liquids from coal, all from the West. We compared two water supply scenarios: a base case with water supply estimates as shown in Table A-1 of the Appendix and a more restrictive scenario with surface supplies available only in Idaho, western Montana, and North Dakota.

The difference between the value of the objective function (the minimum cost of energy production) in the two water-supply cases was only 0.6%. That figure applies to the total US, however, and is higher for the 10-state western region.

In both cases, about 33 000-MW coal-fired capacity and 1 300-MW nuclear capacity were sited in the 10 western states. Most of that new capacity was in the Southwest, reflecting demand growth in California and other Sunbelt states and the favorable economics of coal transportation by rail compared to mine-mouth generation and long-distance electricity transmission. Coal gas, and liquids facilities were sited in eastern Montana and western North Dakota, reflecting the abundance of low-cost, strippable coal and lignite reserves in the Northern Plains. In the more restrictive water supply scenario, about 3 000 MW of electric capacity shifted from eastern Nevada to the Utah portion of the Great Basin, and most of the coal gas plants in Montana shifted to North Dakota.

In both water supply scenarios, only 100% wet cooling was used at electric plants. Coal liquid facilities employed the maximum allowable fraction of dry cooling. Incremental dry cooling costs, however, were calculated for conventional technologies and may understate the potential for dry cooling with ammonia phase change loops.

Table 5 shows incremental water consumption for the two water supply scenarios for regional energy production in the 10 western states. Total incremental consumption is almost 700 000 acre-ft/yr. This is a relatively small amount compared to the approximately 25 million acre-ft/yr currently used for irrigation. For more disaggregated comparisons, the water demands of the energy sector still seem tolerable. As an extreme case, the model placed over 16 000 MW of new coal-electric capacity in Arizona (the figure is probably on the extreme high side) with concomitant demands for about 200 000 acre-ft/yr, representing less than 4% of water use in irrigation in that state.

One region where water scarcity presents a potential bottleneck to development is oil-shale country. The shale oil production scenario of 2 quad/yr is equivalent to about 900 000 bbl/day. With an 8 000 acre-ft/yr per 50 000 bbl/day Tosco II process facility, water consumption for shale oil production is about 150 000 acre-ft/yr. Because the richest oil-shale deposits are in Colorado, development places considerable pressure on the water resources of the Yampa and White River subbasins of the Colorado River (region 35 of Table A-1).

Process change might alleviate some problems. The Paraho direct process uses as little as 2 500 acre-ft/yr per 50 000 bbl/day plant and modified insitu processes may produce a surplus of mine water (23,24). On the other hand, shale oil demands are expected to grow rapidly around the turn of the century. While 2 quads a day may be optimistic for 1995, by year 2015 Exxon forecasts demand for 14 quads shale oil or about 7 million bbl/day (25). Unlike production of electricity or synthetic fuels from coal, tapping lesser grade deposits in other regions or transporting the oil shale are economically unattractive.

In summary, water acquisition by energy firms must overcome a variety of physical, economic, and institutional hurdles. Because of the variety of water supply and demand alternatives available to the energy sector, the physical and economic hurdles generally appear surmountable. This is particularly the case with coal-using sectors (electricity generation and production of synthetic gas and liquids) that have the additional advantage of siting flexibility. One may anticipate water-related constraints to shale oil production in the next century, but these are contingent upon uncertain technological developments and the persistence of restrictions on interbasin transfers. Only institutional considerations approach the status of a constraint to the energy sector. In a "crash" national drive for energy independence, such considerations are unlikely to affect the scale of development in the West as a whole, but rather direct development to or from certain basins or states.

Let us consider then the institutional framework governing water allocation with emphasis on those aspects related to energy development.

Institutional Considerations

Institutional Change

For our purposes, "institutions" refer to the entirety of laws, rules, administrative procedures, organizations, customs, habits, and other social forms that evolved to govern water allocation. The existing institutional machinery for western water was constructed gradually around the turn of the century for the principal purpose of appropriating virgin water and protecting established usufructuary rights. These institutional arrangements must now address the new tasks of reallocating water sources that are fully appropriated and of insuring the efficient use of increasingly scarce water supplies. These new tasks require institutional change at a minimum and to some extent the selective creation of entirely new institutions. Change can be observed throughout the region. Let us review some prominent examples, indicating the energy sector's reactions to and influences on the directions of change.

Instream Values. Laws requiring that water physically be taken from the streams to establish a beneficial use reflect the water development era in the West. With the advent of full appropriation, some states altered their statutory codes or judicial rules to confer legal status upon instream uses like fishing and canoeing, recreational or simply aesthetic appreciation. In addition, Federal legislation such as the Endangered Species Act has limited streamflow depletion. Recently, litigation between the Missouri Basin Power Project (MBPP) and the National Wildlife Federation (and other litigants) led to an injunction halting plant construction (26). MBPP settled out of court and agreed to curtail water use, modify reservoir operating procedures, cease further acquisition of irrigation rights, and establish a $7 million whooping crane habitat trust fund.

Increasingly, the states and the Federal government are comparing the value of traditional consumption of water with newly asserted instream uses. These comparisons imply additional risk and uncertainty for water and energy developers.

Water Markets. As long as water remained a commodity that could be newly appropriated by diverting a streamflow or sinking a well, there was little need for procedures allowing the buying and selling of water rights. Some states in protecting established rightholders during the development era even made water rights appurtenant to the land and legislatively prohibited their severance and transfer to other uses. But as new water demands arose in fully appropriated basins, transfers from existing users became a common source of water supply. This buying and selling of water rights has led to the development of rudimentary but recognizable water markets, with market specialists developing in some basins and states.

Many water transfers incur significant transaction costs. For example, in addition to the payments to irrigators reported above, the Intermountain Power Project (IPP) spent several million dollars for engineering studies and legal fees. The transaction costs associated with IPP's water acquisition average $75/acre-ft. Energy companies can afford the significant costs incurred in many water transfers. This leads to the clarification through case law of the terms governing transfers and the increased marketability of water rights.

Interstate Transfers. A major element underlying western water institutions during the development era has been state sovereignty over the water resources within its boundaries. When rivers such as the Colorado and Rio Grande flowed through or by several states, extended and expensive negotiations resulted in interstate compacts and judicial decisions dividing the expected flow of the river among the states. Thus, state sovereignty prevailed. Many state constitutions confer ownership of the waters within the state to the people of the state.

In recent years, this territorial supremacy over water has been assaulted. Two lawsuits, *Colorado v. New Mexico* (27) and *El Paso v. Reynolds* (28), if successful, would take water from a fully appropriated surface water basin and a closed groundwater basin, respectively, and move it for use in an adjoining state. According to a principal participant in the latter suit, a successful interstate transfer would undermine the foundation of the interstate compacts. Another example of the growing pressure for institutional change in this area is the persistent effort by Energy Transportation Systems, Incorporated (ETSI) to construct a slurry pipeline for shipping coal from Wyoming to Arkansas and beyond. After encountering difficulty in obtaining Wyoming water, ETSI recently reached a novel agreement with the government of South Dakota that may lead to the export of 50 000 acre-ft/yr of water from Lake Oahe and South Dakota sovereignty.

The capital cost of conveyance limits the frequency of such interstate ventures. However, the energy industry, with its considerable ability to pay for water, especially for coal slurry pipelines and oil-shale development, will be at the forefront of pressure to allow for interstate transfers. One consequence may be the evolution of stronger regional water management institutions.

Quantification of Reserved Rights. As long as unappropriated water remained during the water development era, both Indian and other Federal reserved water rights could remain unquantified without pressing too strongly on competing claimants for water. However, with the advent of full appropriation, existing appropriators increasingly comprehend the uncertainty that these paper rights pose for their own access to "wet water." The consequence has been increased interest in quantification (and therefore limitation) of reserved rights. Examples include the judicial decision in the *United States v. New Mexico* (29) and recent legislation (enacted and proposed) in Congress and various state legislatures. Some Indian leaders, recognizing the increased pressure, are concerned that litigation, legislation, and negotiation are inadequate and that the time has come for Indian tribes to exercise their rights.

Water Development Cost Sharing. A strong indicator of the transition from water development to water management as the central societal task is the impending change to a Federal-state, cost-sharing mechanism to finance future water development projects. Although the exact formula is still undetermined at this writing, bipartisan congressional bills garner even the support of legislators from the western states. During most of this century, when the reclamation ethic was dominant and an accepted societal objective was "to make the desert bloom," western politicians needed no "state cost sharing" to secure Federal funding. The subsidization of western water users, particularly in agriculture, was once the accepted political practice, but the future offers abundant alternative management techniques (30).

Fundamental Issues

During the transition period when new water management rules are being formulated and institutionalized, water users, particularly relatively new participants such as the energy industry, must recognize several related issues at the heart of water resource allocation. First, we consider objectives in water allocation. Is water (or, should it be) simply another commodity? Does water carry symbolic importance far exceeding its material value? Second, we review questions of conflicting claims to water ownership. Finally, we discuss the appropriate form of water management institutions. Alternative management forms range from pure laissez-faire market schemes to complete centralization of water allocation by state agencies or independent public corporations. There is no private or public concensus on these subjects at present, but developing attitudes will shape institutional conflicts and changes.

Societal Attitudes Towards Water. Some economists argue that water is like any other commodity. As it becomes increasingly scarce, it should be allowed to increase in market price and be allocated by market processes. Other students note that water is

> the object of a very complex structure of evaluations, rituals, superstitions, and attitudes. It has been the subject of sacred observances from very early times in human history.

The latter characterization (31) contributes to what is termed the "water is different syndrome" in which social attitudes require that water be treated differently than most other natural resources. A core element in this view is the indispensability of water to life itself. While there may be a high degree of substitutability in water uses such as the energy production technologies discussed earlier, it is inescapable that for basic life processes water must be present in biologically "fixed proportions." This core fact, combined with man's aquatic origin and agricultural heritage, easily accounts for a historically different set of social values being attached to water.

There is considerable evidence that this valuation structure survives today in the symbolic importance that Indian tribes attach to water rights (32) and the emotional intensity with which rural agricultural water users resist losing control of water. Water is valued not only for its historical importance and indispensability to life; in the semi-arid West it is also seen as the critical controlling element of economic destiny. Loss of control over water is seen as a forfeiture of future opportunity by those conditioned to periodic drought. Public attitudes in the less arid sections of the country do not appear as sensitive. But, faced with a future condition in which the demand for their native water exceeds their supply, the same latent valuations may manifest themselves. For example, in a recent public poll measuring attitudes on water, 70% of the respondents did not even wish to "consider selling any extra water" to Texas and Oklahoma (33).

Regardless of the depth and extent of the intangible social value structure that overlays the tangible substance, water, water remains increasingly scarce relative to the demands placed upon it. To the extent that water is important to the material well-being of society and that material well-being is socially important, water must be allowed, and even encouraged, to move to its highest valued economic use. To deny that movement is to forfeit the economic gains such movement makes possible. A corollary asserts that past practices of subsidizing water use must dissipate as a matter of public policy. Increasingly, water must be valued at its actual opportunity cost if it is to be managed wisely at all levels within the economy.

A minimal conclusion to the above discussion is that the evolving institutions for managing water (again contrasted with simply developing it) must take account of entrenched attitudes. If, on the one hand, these attitudes are viewed . anachronistic, then at a minimum, successful management institutions must incorporate a strategy for changing this element of the public attitude towards water. If, on the other hand, the view that "water is different" is accepted as supportable, or at least as given, then the evolving management structure must allow expression and some measure of control for proponents of this view.

Unresolved Ownership Problems. The most prominent problems of this type are the Winters doctrine claims of the various Indian tribes and other reserved rights advocated by the Federal government. Although many Indian leaders resist quantification as a diminution of their claim to water, the pressure for quantification is increasing. Even if the tribes successfully resist a fixed and final quantification of their rights, it seems likely that a minimum resolution of this question will require agreement on a formula for determining ownership. Current litigation utilizes the "practicably irrigable acreage" criterion promulgated in the *Arizona v. California* (34) decision of 1963. Although this criterion is an anachronism in light of modern economic conditions and although the inclusion of economic factors in the interpretation of the term practicably is resisted by Indian leaders, the criterion nevertheless provides a formula for determining the extent of Indian rights. Unless an alternative formula is proposed and agreed to by all interests, the pressure for elimination of the uncertain title to water created by the existence of reserved rights is likely to force quantification.

A second ownership question, not claiming public attention as forcefully as that of reserved rights, promises to play an even more fundamental role in the development of water management institutions. Is water public or private property? On its face, at least in the water law of most western states, this question is settled. Water has both a statutory and constitutional foundation in the law of most western states as belonging to the public with a usufructuary right granted to individuals to use the water for private purposes. For practical purposes, however, it is the latter title to water that dominates the actual allocation and control of water as well as the terms of compensation. Most state water administration institutions are confined to a regulatory authority to review private water transactions. Some structures, such as Texas groundwater law, do not even allow for this regulatory authority. Yet, there are signs of potential and growing conflict between these alternative institutional forms of ownership.

As long as new uses for water could be accommodated without retirement or threat to other uses, public sentiment tolerated a passive interpretation of public ownership. However, as full appropriation promotes reallocation of water, and as the economic value of water steadily increases, a more active assertion of public ownership and control may develop. The ETSI effort to obtain water for use in an interstate coal slurry line offers an example of this more active public role. In Wyoming, public action prevented what otherwise would have been a private transaction from occurring. South Dakota asserted an active public ownership because the negotiated agreement was with state government rather than with private parties, as a purely passive public ownership philosophy implies. Another example is a recent legislative proposal in Utah that would allow the State Engineer to consider the general economic benefit to the public in granting applications for Colorado River water. Such a criterion could reorder the queue of applicants currently temporally ordered by the date of application.

At this point, the debate over public versus private ownership is chiefly academic. However, increasing conflicts (35) are likely because it arises in large part from different societal attitudes towards water. The resolution of this fundamental ownership question will be central in structuring the form eventually assumed by water management institutions.

Water Management Institutions. One could design a variety of management forms for the allocation and development of water if society were free of the existing institutional structure. A key element in a management scheme is the locus for decisionmaking. At one extreme, some philosophers argue for a pure laissez-faire arrangement in which decisions are made exclusively in voluntary bilateral agreements between individuals, with no individual having authority to bind others to an allocation without their explicit concurrence. At the other extreme, one may idealize centralized decisionmaking. This reflects an organic view of society in which achievement of collective social values is best accomplished through the socially binding decisions of a central unit.

Neither pure laissez faire or complete centralization is ever likely to be a practical scheme for managing water, and certainly society cannot design its institutional structure independent of the existing patterns and past history. Water development in the West exhibits elements resembling both laissez faire and centralized decisionmaking. Diversion of "native water" as well as transfer of ownership and use have been largely a matter of individual initiative and action whereas "project water," particularly for irrigated agriculture, has required centralized funding decisions at the Federal level. The pattern has been decentralized decisions for the water itself, and centralized decisionmaking for the allocation of capital to divert, store, transport, and apply the water.

In an era of broader water management functions, society must examine the suitability and synergism of these contrasting forms for modern tasks. Moreover, the newly emerging water management institutions must be consistent with prevailing social attitudes towards the use and ownership of water. Significant social conflict is likely as institutional changes emerge. In certain states and basins, the institutional hurdle--from an energy perspective--may be severe(36).

Summary and Conclusions

As stated earlier, both the scientific and, to a lesser degree, the lay understanding of the relationship between water and energy in the West has passed through an evolutionary process. In the crisis atmosphere engendered by the 1973 oil embargo, concern mounted over the inadequacy of the naturally occurring physical stocks and flows of western water to meet the large scale demands expected to arise from a burgeoning energy sector. This view yielded to an economic perspective in which reduced projections of energy development were coupled with an increased awareness of energy's considerable ability to pay for its water and the associated feasibility of large scale transfers of water rights. In this context, water has diminished as a regional constraint on energy development although local constraints still might be formidable.

The ability to pay conclusion, however, did not end the evolution in understanding. Although water is higher valued in energy uses and will "run uphill to money," societal concerns about the shifting ownership, control, and use of water have led to institutional conflicts that challenge the market directed movement of water. Moreover, the increasing value of water focuses attention on unresolved issues surrounding water in the West. Particular importance is attached to ownership questions, as embodied in Indian and Federal reserved rights, and to management questions such as state sovereignty in prohibiting interstate movement of water. Despite substantial evidence that the institutions governing water in the West are themselves evolving, significant problems remain and must be addressed.

We conclude this paper with two observations based on the preceding discussion. First, energy's use of water does not really present a unique set of problems. Instead, the key issue in western water affairs at this juncture is the changing nature of the western water institutions themselves. Although energy is a major actor in this evolving political environment, it cannot be treated in isolation from the broader context for water. Institutional dynamics influence, and are influenced by the energy sector's use of water.

Second, as the water institutions in the West are reshaped to perform water management functions in contrast to the more narrow water development tasks historically pursued, it is unclear to what degree active governmental intervention will be needed, particularly by the Federal government. Arguments exist for a substantial Federal role as trustee for Indian tribes, owner of reserved rights, arbiter of state disputes, and funder of development activities. However, counterarguments point to the need for decentralized basin or subbasin authority because the informational capacity to match societal purposes with the occurrence of the physical resource is greatest at lower governmental levels. The search for institutional solutions to these counterforces is a prominent and difficult policy issue. It is very likely that the stresses will continue to grow before acceptable solutions are found.

Appendix

LACUMS is a partial equilibrium model of coal markets with particular emphasis on coal supply, electric utility capacity expansion, and environmental regulation of air quality and water quantity (37). LACUMS is solved through mathematical programming and is driven by exogenously specified energy demands and supply costs. The model is highly regionalized involving the division of the US into many coal producing regions, coal demand regions, and electricity consumption regions--in addition to the environmental regions associated with airsheds and river basins.

Water demand for electricity generation and coal liquefaction is treated as a three-step function with water conservation by partial dry cooling at higher costs (18). Water supply to the energy sector is described as a three-step function in 30 regions of 10 western states (Table A-1). The three steps represent potential supplies to the energy sector: unallocated surface water, transfered irrigation water, and groundwater. The acquisition cost of surface water is $20/acre-ft. Irrigation water costs $192.50/acre-ft (on an annual basis); groundwater, $211.75/acre-ft. The water quantity data were developed in an ad hoc manner by consideration of physical data in state water plans and Bureau of Reclamation planning documents, compacts allocating interstate stream flows, and state laws governing groundwater depletion and water transfers to industrial uses.

One must consider the results of the LACUMS analysis with some reservation. For example, it is a static analysis in which the demands of the municipal and non-energy sectors are fixed at current levels. There is a need to represent more steps in the water supply functions and to conduct sensitivity analyses of water-related input data. Nevertheless, it portrays the tradeoffs among the costs of energy transportation, water supply, and water conservation (dry cooling) and allows some comparison between the water demands of the energy sector and basin supply.

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Table 1. Water use for energy conversion[a] (A-ft/yr)

	Process	Cooling	Mining and Waste Disposal	Flue Gas Desulfurization	Total
Coal Gasification (275×10^6 Mcf/d at 90% cf)					
Lurgi	550	5 050	1 350	800	7 750
Hygas	1 700	3 150	1 000	350	6 200
Coal Liquefaction (55 000 b/d at 90% cf)					
Synthoil	800	4 500	2 100	--	7 400
Shale Oil (55 000 b/d at 90% cf)					
Tosco	850	2 600	4 700	1 150	9 300
Paraho Direct	(350)	3 700	1 700	800	5 850
Electricity Generation (1 000 MWe)					
Coal (65% cf)	--	7 550	750	1 250	9 550
Nuclear (57% cf)	--	11 300	500[b]	--	11 800

[a]Water use for coal conversion calculated for a southwest site with subbituminous, high ash, low sulfur coal.

[b]Excludes water use for uranium mining and milling.

Legend: Mcf/d = thousand cubic feet per day
b/d = barrels per day
MWe = megawatt electric
cf = capacity factor
-- = not applicable

Source: Adapted from Probstein and Gold (10) and Abbey (6).

Table 2. Cost of cooling alternatives at coal-electric plants for two sites in the western US ($1978)

	% Wet	$/kW	mills/kWh[a]	Break-Even Water Cost[b] ($/A-ft)
Farmington, New Mexico	100	23	1.11	-----[d]
	40	44	2.21	1 200
	10	57	2.86	1 570
	0[c]	48	4.07	8 770
Colstrip, Montana	100	23	1.14	---
	40	43	2.16	1 200
	10	57	2.68	1 260
	0[c]	47	4.02	9 560

[a] At 80% annual capacity factor; exclusive of water-use costs.

[b] Assumes evaporation of 0.45 gal/kWh with 100% wet cooling.

[c] High back pressure turbine used.

[d] Not applicable.

Source: Adapted from Hu, Pavlenco, and Englesson (11).

Table 3. Freshwater consumption in ten western states in 1975 (10^6 gal/d)

	Irrigation	Public Supplies	Rural Use (Domestic and Livestock)	Self-Supplied Industrial	Thermo-Electric Power
Arizona	5 400	200	66	210	41
Colorado	5 100	110	37	59	12
Idaho	4 700	34	27	160	2
Montana	2 700	49	55	12	nil
North Dakota	150	29	36	24	19
Nevada	1 500	52	14	71	22
New Mexico	1 400	83	56	85	33
South Dakota	180	14	100	6	3
Utah	2 200	130	14	51	8
Wyoming	2 000	46	26	34	24
Total	25 330	747	431	712	164
Per Cent of Total Use	92.5	2.7	1.6	2.6	0.6

gal/d = gallons per day.

Source: Adapted from Murray and Reeves (17).

Table 4. Transfers of water rights to energy firms in the intermount[illegible]

To	From	Quantity for Consumptive Use (A-ft/yr)
Colorado River Basin		
Utah Power and Light Company (Huntington and Emery Plants, Emery County, Utah)	Cottonwood Creek Consolidated Irrigated Company	5 000
	Ferron Creek Irrigation Company	7 000
	Emery County Water Conservation District (under contract from the Bureau of Reclamation)	6 000
San Diego Gas & Electric Company (Sundesert Plant, Blythe, California)	Metropolitan Water District	17 000
	Water rights obtained from purchase of 7 700 acres ranchland in Palo Verde Irrigation District	33 000
Nevada Power Company[a] (Reid Gardner, Moapa, Nevada)	Purchase of a ranch and leasing winter agricultural water	3 500
Nevada Power Company (2 000 MW, Las Vegas, Nevada)	Las Vegas and Clark County Sanitary Districts	43 764 (Sewage treatment plant effluent)
Arizona Electric Power Cooperative (350 MW, Benson, Arizona)	Purchase of 1 500 acres of farmland in Sulfur Springs Valley	7 000 (from wells)
Arizona Public Service Company (4 000 MW Nuclear plant, Wintersburg, Arizona)	City of Phoenix	64 000 (Sewage treatment plant effluent)
Great Basin		
Intermountain Power Project (3 000 MW, Lyndyll, Utah)	Shares in the Delta, Melville, Abraham, and Deseret Irrigation Companies and the Central Utah Canal Company	45 000

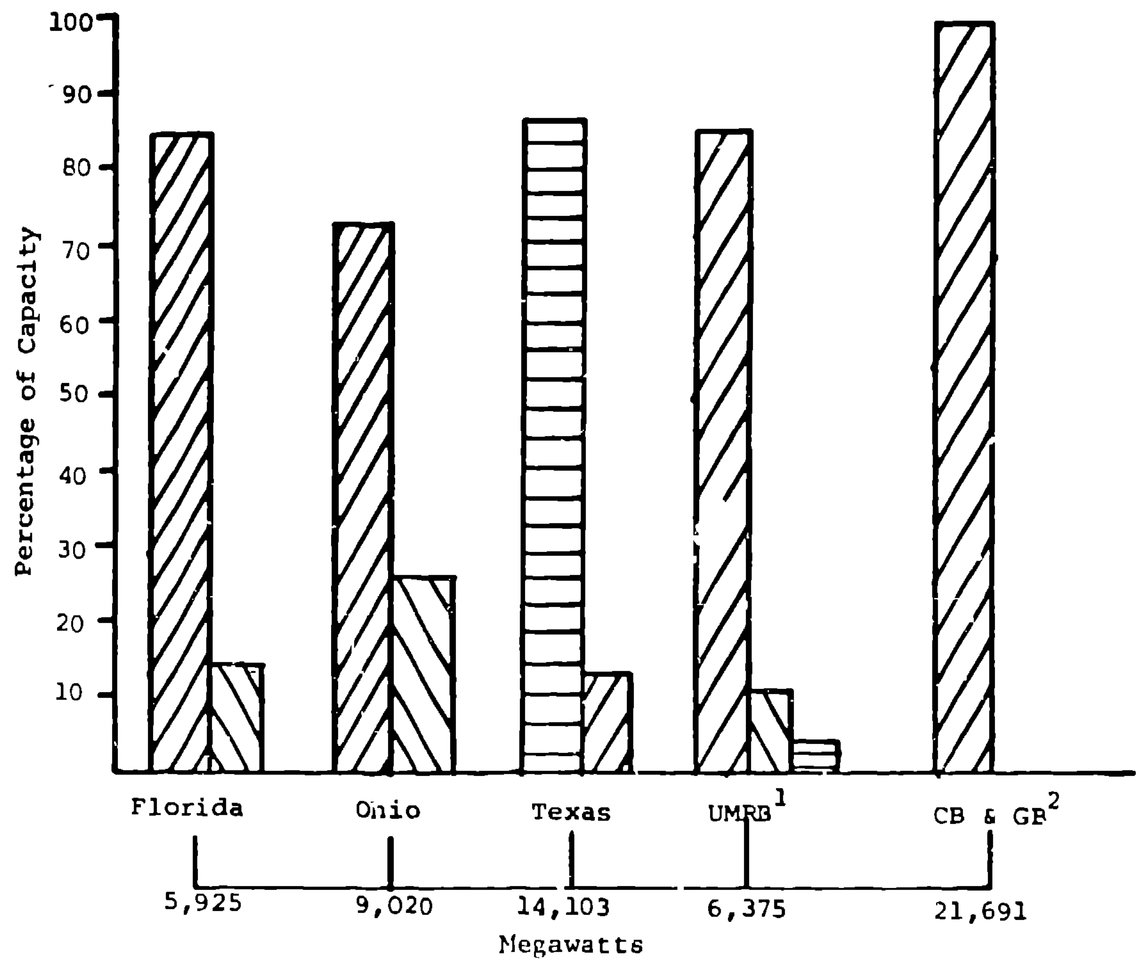
Table 4. continued

To	From	Quantity for Consumptive Use (A-ft/yr)
Arkansas Basin		
Public Service Company of Colorado[b] (1 000 MW, Las Animas, Colorado)	Los Animas Consolidated and Consolidated Extension Canal Companies	8 000 - 10 000
Platte River Power Authority (230 MW, Ft. Collins, Colorado)	City of Ft. Collins and Water Supply and Storage Company (a mutual ditch company)	4 200
Platte River Basin		
Missouri Basin Power Project (1 500 MW, Wheatlands, Wyoming)	Boughton Ditch, irrigated land inundated by by reservoir, and groundwater from Johnson Ranch	6 000
Panhandle Eastern Pipeline Company (coal gas plant, Douglas, Wyoming)	Douglas Reservoir Water Users Association (by financing repairs on a dam on La Prele Creek)	5 000

[a]In negotiation.

[b]Option agreement.

Source: Adapted from Abbey and Loose (18).



Evaporative Cooling Towers

Once Through

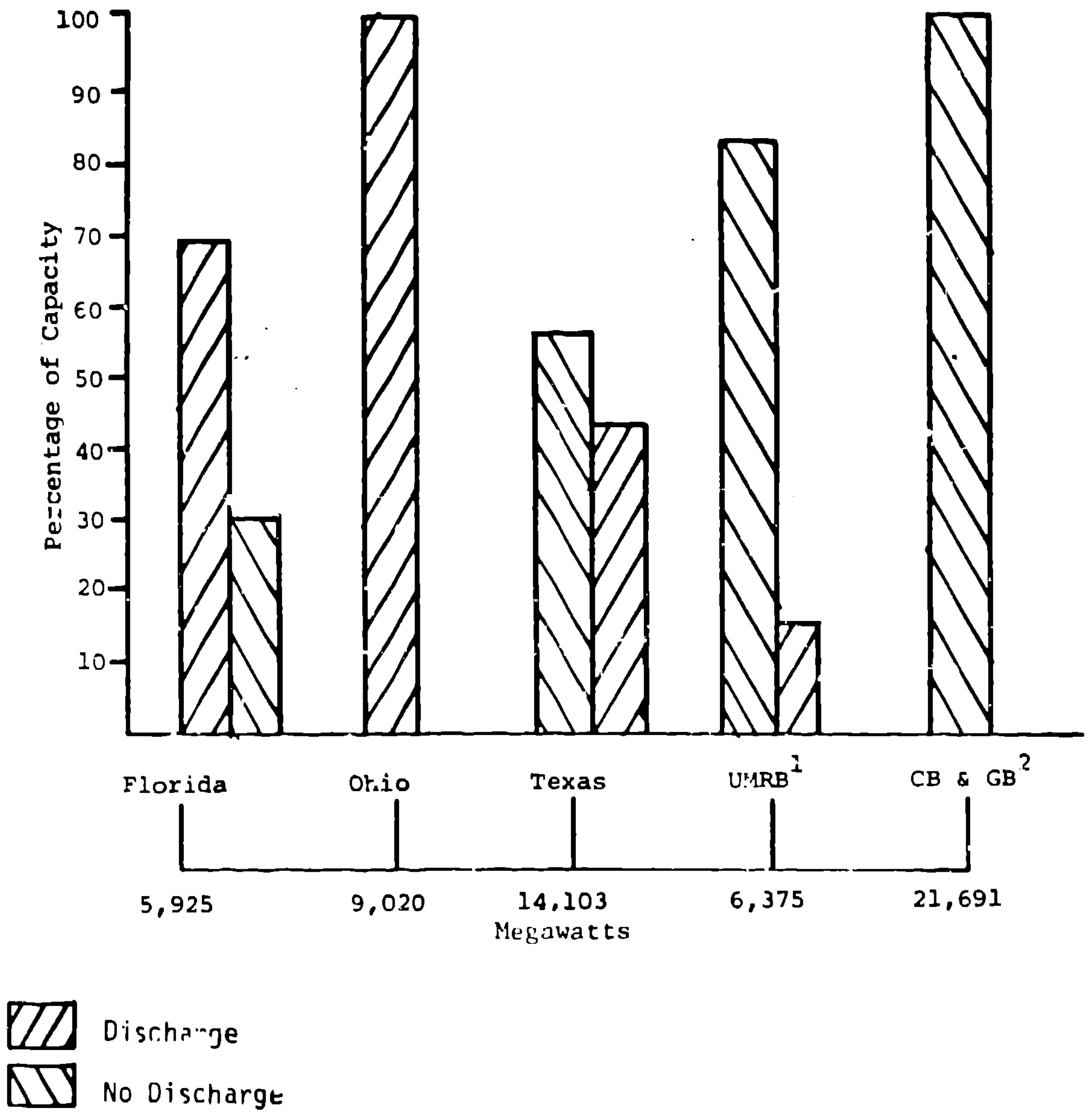
Cooling Pond

[1]Upper Missouri River Basin

[2]Colorado Basin and Great Basin

Source: Abbey and Lucero (7)

Fig. 1: Cooling systems at coal-fired and nuclear power plants in selected states and river basins, 1980-1989.

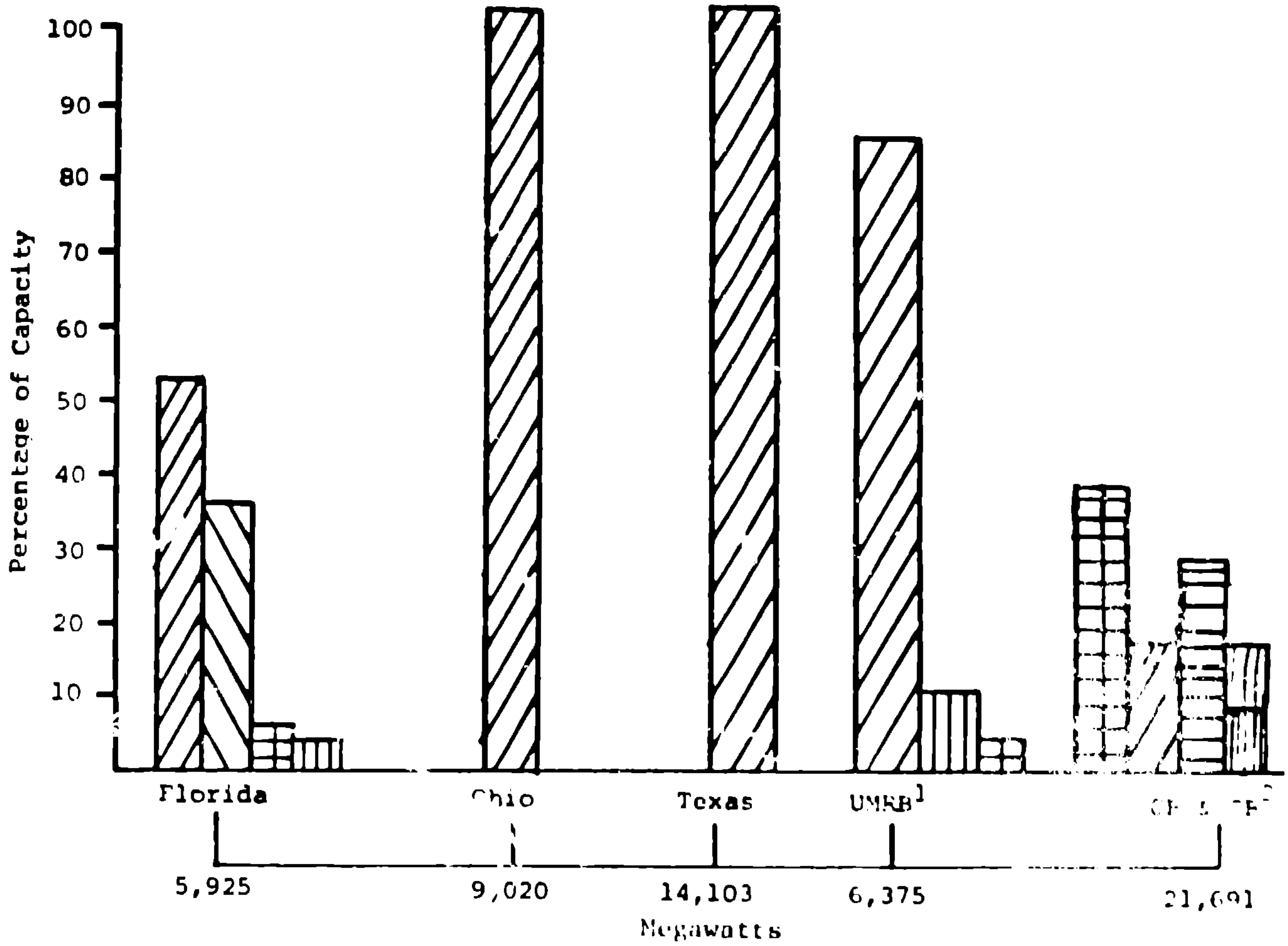


[1]Upper Missouri River Basin

[2]Colorado Basin and Great Basin

Source: Abbey and Lucero (7)

Fig. 2: Discharge at coal-fired and nuclear power plants in selected states and river basins, 1980-1989.



Surface Water

Ocean

Wastewater

Groundwater

Water Purchased from Irrigators

[1]Upper Missouri River Basin

[2]Colorado Basin and Great Basin

Source: Abbey and Lucero (7)

Fig. 3: Water sources for coal fired and nuclear power plants in selected states and river basins, 1980-1989.

Table 5. Results of LACUMS analysis: water use for energy conversion in ten western states (10^3 A-ft/yr)

Coal Demand Region[a]		Type of Water	Base Case	Restricted Case[b]
29	(AZ-Salt)	Surface	24	---[c]
		Transfer	---	24
31	(AZ-NW)	Transfer	4	4
		Groundwater	38	38
32	(AZ-Yuma)	Transfer	131	132
39	(Idaho-Snake)	Surface	4	4
41/42	(MT-Lower Yellowstone	Surface	90	---
		Transfer	---	52
43	(NV-Elko)	Transfer	39	39
44	(NV-Truckee)	Transfer	72	67
45	(NV-Las Vegas)	Surface	44	---
47	(NM-Abq)	Surface	o	---
		Transfer	---	9
48	(NM-Lower Rio Grande)	Surface	18	---
		Transfer	---	18
58	(ND-Upper Missouri)	Surface	46	83
50	(Utah-Great Basin)	Surface	10	---
		Transfer	7	62
37	(Colorado-Yampa)	Surface	80	---
		Transfer	---	80
51/52	(Utah-East)	Surface	48	---
		Transfer	---	48
65	(Wyoming-Green)	Surface	16	---
		Transfer	---	16
	Total	Surface	389	87
		Transfer	253	551
		Groundwater	38	36
		Grandtotal	680	676

[a]Term(s) in parentheses indicate approximate geographic location of region.

[b]The surface water supply option is eliminated except in North and South Dakota and the Columbia River Basin regions of Montana and Idaho.

[c]None.

Table A-1. Water supply estimates by coal demand region and water supply category (10^3 A-ft/yr)

State/Region		Streamflows	Transfers	Groundwater
Arizona				
29	Phoenix (Salt)	240	1 091	---
30	Little Colorado	-----[a]	8	50
31	Colorado-Grand Canyon	-----	4	48
32	Colorado-Yuma	-----	876	180
33	Tucson	-----	123	103
Colorado				
34 38	Platte/Arkansas	-----	2 063	---
35	Green (Yampa/Whte)	98	113	17
36	Upper Colorado Mainstem	88	969	NA[b]
37	San Juan/Rio Grande	-----	812	NA
Idaho				
39	Central and Upper Snake	4 500	7 000	---
40	Lower Snake/Clarks Fork		No Constraint[c]	
Montana				
41	Columbia		No Constraint	
42	Upper Missouri	300	3 160	NA
61 62	Yellowstone	355	1 650	40
Nevada				
43	Great Basin (Elko)	-----	560	70
44	Reno (Truckee, Carson)	-----	275	335
45	Las Vegas (Colorado)	44	-----	---
New Mexico				
46	San Juan	80	80	2
47	Albuquerque (Rio Grande)	40	135	380
48	Pecos/Lower Rio Grande	70	1 500	400
North Dakota				
58	Upper Missouri	233	-----	40
59	Souris/Red		No Constraint	
South Dakota				
60	Upper Missouri	233	-----	40
Utah				
49	Weber/Jordan	-----	413	---
50	Virgin/Great Basin	10	1 902	85
51 52	Green/Colorado Mainstem	135	560	30

Table A-1. continued

State/Region		Streamflows	Transfers	Groundwater
Wyoming				
53	Platte	-----	580	---
54	Powder/Tongue	217	151	40
63 64	Yellowstone	325	1 029	NA
65	Green	25	242	NA

[a]Nil.

[b]Not available.

[c]For several regions surface water supplies are taken as infinite. These regions lack coal resources, are predominately rugged in terrain, and/or are traversed by mighty streams.

Source: Adapted from Abbey and Loose (18).